Smoothing Pits on EUV Mask Blanks by Ion-beam Deposition

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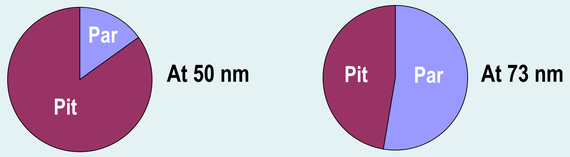
Introduction

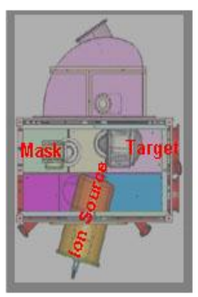
- Pit-type defects in extreme ultraviolet (EUV) mask blanks have consistently been a major hurdle in the effort to produce defect-free mask blanks [1]. The defects need to be smoothed to a depth of ~1 nm or less to render them unprintable [2].
- As defects become smaller (>50 nm), pit-type defects become the major contributors, as opposed to particle-type defects at larger sizes (>73 nm).



- To improve substrate quality, SEMATECH investigated the space map of the Veeco Nexus low defect density (LDD) deposition tool and tested various substrate angle/target angle (SA/TA) combinations for uniform depositions.
- A space map was generated to outline regions of good uniformity, and standard deposition conditions and pit smoothing deposition conditions were evaluated for smoothing power and reflectivity at normal and low pressures.

Current ML Deposition Tool and Process

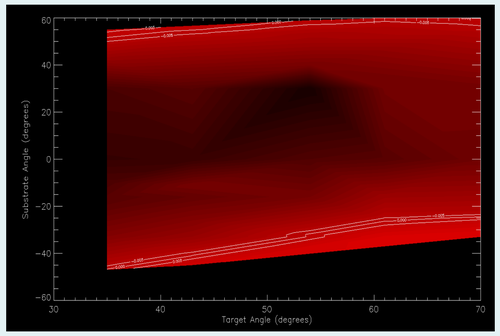
Process module of Veeco Nexus LDD tool



- ✓ RIM-210 ion source
- ✓ RF Ar plasma
- ✓ Ar flow rate ~17 sccm
- ✓ Ar ions extracted at 600 eV, 300 mA
- ✓ Base pr ~ 0.14 mTorr
- ✓ Working pr ~ 10^{-8} Torr
- ✓ 12" dia. Si, Mo, Ru water-cooled targets
- ✓ Mo/Si thickness ~ 3/4 nm respectively
- ✓ Typical deposition rate ~ 1 minute/layer

Uniformity Space Map

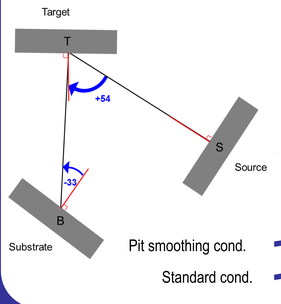
- For print uniformity, the center wavelength of the mask should not vary by more than 0.1% across the mask area.

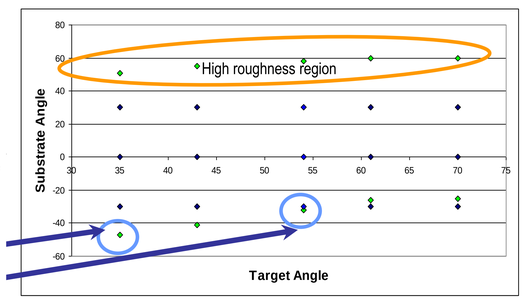


- Figure shows map of uniformity over the SA/TA angle range available in the tool.
- White contours outline regions where adequate uniformity can be achieved (0.05%, 0.00%, -0.05%).
- Very narrow region (~3°) of uniform deposition.

SA/TA Combinations

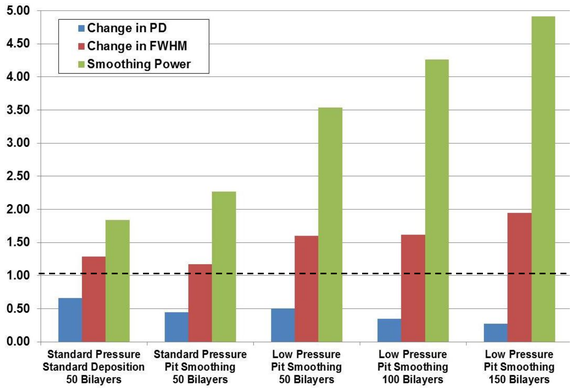
- To achieve adequate uniformity, tool must operate in two narrow bands of substrate angles at relatively large positive and negative tilts.
- Experimentally the substrate angles of the upper branch lead to high roughness films.
- Standard and pit smoothing deposition conditions from the lower branch were selected for defect characterization.





Pit Decoration Results

- With pit smoothing, the pit depth (PD) decreases in value, and full-width half-maxima (FWHM) increases in value.
- Low pressure deposition leads to greater smoothing, as does deposition of more bilayers.
- A saturation pit depth of 1.1 nm was reached after depositing 150 bilayers at low pressure pit smoothing conditions.



Aspect ratio (AR)

$$AR = \frac{PD}{FWHM}$$

Smoothing power (σ)

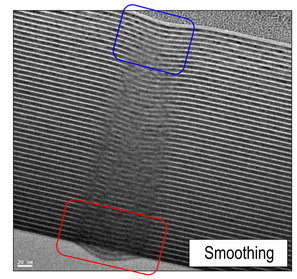
$$\sigma = \frac{AR_{initial}}{AR_{final}}$$

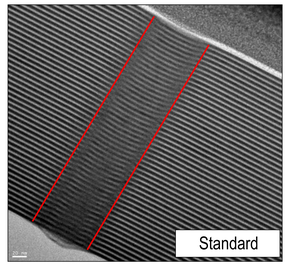
Saturation depth = Minimum PD before pit redecoration

Deposition Condition	Change in PD	Change in FWHM	Smoothing Power	Saturation Depth (nm)
Normal Pr, Standard cond.	0.66	1.29	1.84	3.4
Normal Pr, Pit smoothing	0.44	1.17	2.27	3.1
Low Pr, Pit smoothing	0.50	1.60	3.54	N.R.
Low Pr, Pit smoothing (2x)	0.35	1.61	4.26	N.R.
Low Pr, Pit smoothing (3x)	0.27	1.95	4.91	1.1

Transmission Electron Microscopy Data

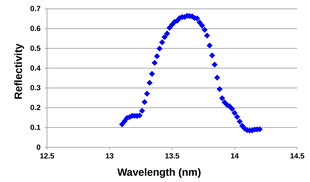
- TEM cross-sectional images were taken after depositions at standard pressure.
- The disruption to the multilayer is smoothed during deposition under pit smoothing conditions, whereas it propagates from the substrate to the multilayer surface under standard conditions.



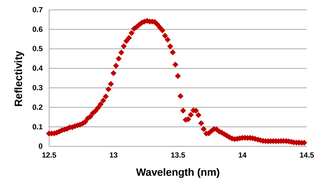


EUV Reflectivity

- A plate deposited using standard condition and pressure was compared with a plate deposited (3x) using pit smoothing condition at low pressure:
  - Standard cond., normal pr.: Average R_{max} = 66.47 ± 0.0026 @ 13.59 nm
  - Pit smoothing, low pr.: Average R_{max} = 64.30 ± 0.0030 @ 13.24 nm



Standard Pressure, Standard conditions



Low Pressure, Pit smoothing, 3x

Future Work

- Selected pit smoothing plates will be imaged on the actinic inspection tool (AIT) at Berkeley to determine printability.
- Evaluation of Xe and Ne working gases is currently in progress.
- Particle decoration and defectivity with more bilayers will also be investigated.

Summary and Conclusions

- SA/TA maps were outlined for the Veeco Nexus LDD tool, and negative substrate angles were found to give good roughness and uniformity.
- Lower substrate angles resulted in better pit smoothing than higher ones, and depositions at lower pressure gave even greater smoothing. This is likely due to less scattering at lower pressures.
- More bilayers enhanced smoothing and took pits to about 1 nm deep.

References:
[1] A. J. Kadaksham, et al., *Proc. SPIE* **7969**, 79690Z (2011)
[2] E. M. Gulkinson, et al., *J. Vac. Sci. Technol. B* **20**(1) (2002) 81.